THE EFFECT OF SWEDISH TETHERS ON THE PERFORMANCE OF REAR FACING CHILD RESTRAINTS IN FRONTAL CRASHES

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ABSTRACT

Rear Facing child restraints (RFCR) have various component designs which can couple the restraint to the vehicle. Swedish tethers, which link the upper portion of the child restraint to the vehicle floor, prevent rearward rotation in rear impacts and during rebound in frontal crashes. They also simplify installation of restraints by allowing better control of the installation angle and removing the need of spacer devices. The objective of this study was to test the effect of Swedish tethers on RFCR in frontal crashes. The tethers reduced forward excursion and rotation, and had a positive but minor effect on injury values. The more secure attachment to the vehicle caused by the Swedish tether could also be beneficial in other crash types.

INTRODUCTION

The vehicle belt, lower LATCH belt, or ISOFix anchors serve as the primary components which attach Rear Facing Child Restraints (RFCR) to the vehicle. There are other devices, however, which can be used in addition to the primary components. Anti-rotation legs, Australian tethers, Swedish tethers, the ISOFix base, and anti-rebound bars are each designed to change the kinematics of the child restraint in different crash types.

Federal Motor Vehicle Safety Standard (FMVSS) No. 213, "Child restraint systems," requires RFCRs to meet the performance requirements of the standard when secured to the standard test seat assembly using (1) the lap belt only or (2) the lower LATCH (Lower Anchorages and Tethers for Children) anchorages only. NHTSA does not use a means supplemental to the lap belt/lower LATCH anchorages, such as a tether or a bar, of securing RFCR to the seat assembly in the agency's compliance test. In the past, NHTSA found that a very high percentage of parents did not use a supplemental tether strap to secure their child seats even when they knew the strap was needed to provide their child protection. The agency concluded that there was a strong likelihood that a tether or a bar would be misused with the seat, and that FMVSS No. 213 should thus require that child restraints must meet minimum requirements of the standard without supplemental tethers.

Swedish tethers prevent rear rotation in rear impacts and during rebound in frontal impacts [1]. They link the upper portion of the child restraint to the vehicle floor, and may also have benefits in non-frontal crash types by more rigidly attaching the RFCR to the vehicle [2,3]. They can be attached to built-in anchor points or to the front seat base structure. The tether may reduce excursion in side impacts (lateral) and rollovers (upward/rearward).

In addition to the effect it may have in vehicle crashes, the tether may also have benefits during installation. RFCRs have a recommended range of child restraint angles. The RFCR angle should be approximately 45 degrees (with respect to vertical), but no greater [3]. Since young children cannot hold their heads upright due to their weak neck musculature, the reclined angle prevents the head from flopping forward and cutting off the airway. At angles greater than 45 degrees, however, the child restraint provides less support for the head and neck. Variations in child restraint design, vehicle seat design, attachment equipment (LATCH, 3 pt belt), and the location of attachment anchors result in many RFCRs positioned at incorrect angles [4]. The most common method, which allows adjustment of the angle, is to place a spacer (typically rolled up towels or foam noodles) under the base of the RFCR near the seat back (Figure 1). Swedish tethers provide the opportunity to control and easily adjust this angle.

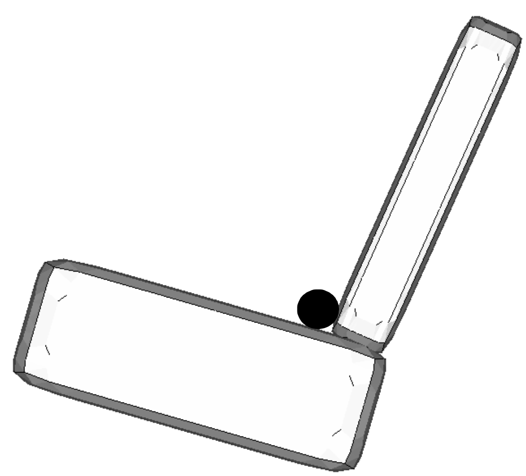

Figure 1. Schematic of RFCR with spacer placed under base to correct installation angle.

It is expected that Swedish tethers would have a minimal effect prior to rebound in frontal crashes because they are not rigid and would go into slack upon impact. However, the tension in the tether and the absence of the spacer may change the initial position of the child restraint and alter its interaction with the vehicle seat. The objective of this study was to test the effect of Swedish tethers on RFCR in frontal impacts.

METHODS

Six frontal sled tests were performed to measure the response of a restrained dummy in rear facing child restraints with and without a Swedish tether. All tests were conducted at a 49 km/h impact speed with an acceleration pulse similar to that specified in FMVSS 213 (23g peak, 90 ms duration). The tests were performed on a vehicle buck that represented a popular minivan. A third row bench seat and seat back were rigidly attached to the buck to create a durable, consistent seat system.

The CRABI 12 month old dummy was used to represent the child occupant. The dummy was equipped with head, chest, and pelvis accelerometers as well as upper and lower neck load cells. Electronic data were sampled at 10,000 Hz and were filtered per Society of Automotive Engineers (SAE) Recommended Practice J211. The tests were recorded at 1000 frames/sec with side and overhead digital video cameras.

Three convertible child restraint models were tested in the rear facing orientation: the Britax Roundabout, the Evenflo Comfort Touch, and the Safety First Comfort Ride. Each child restraint was restrained using the lower LATCH belt in two restraint conditions a) with and b) without a Swedish tether. The Britax Roundabout manual states that the upper tether, typically used as the tether when forward facing, can also be used as a Swedish tether when rear facing. The upper tether was used as a Swedish tether in the Evenflo and Safety First seats as well, although it was not instructed by the manual. All conditions had identical initial angles (40 ± 0.5 degrees, measured with respect to vertical at the child's back). The 40 degree value was chosen because children at 12 months of age (the size of the dummy used in these tests) can sit more upright than newborns.

Without the Swedish tether, the lower LATCH belt was tightened with the foam spacer in place until the appropriate restraint angle was reached. With the Swedish tether, the foam spacer was not used as it was not needed to provide the correct restraint angle. Positioning the child restraint was an iterative process in which the tensions of the lower LATCH belt and Swedish tether were adjusted until the correct angle was attained. The lack of the foam spacer changed the interaction between the restraint and the vehicle seat, but each restraint was installed with the purpose of a) providing a consistent angle and b) attaching the restraint to the vehicle seat as tightly as possible. Figures 2-4 show pre-crash side photographs of the tests, and data on initial positions and tether tensions are included in Table 1. The Head X position was measured with respect to an arbitrary reference point. In tests without the Swedish tether, a secondary tether was placed on the child restraint without any tension, and was only used to prevent the child restraint and dummy from striking the rigidized seat back during rebound.

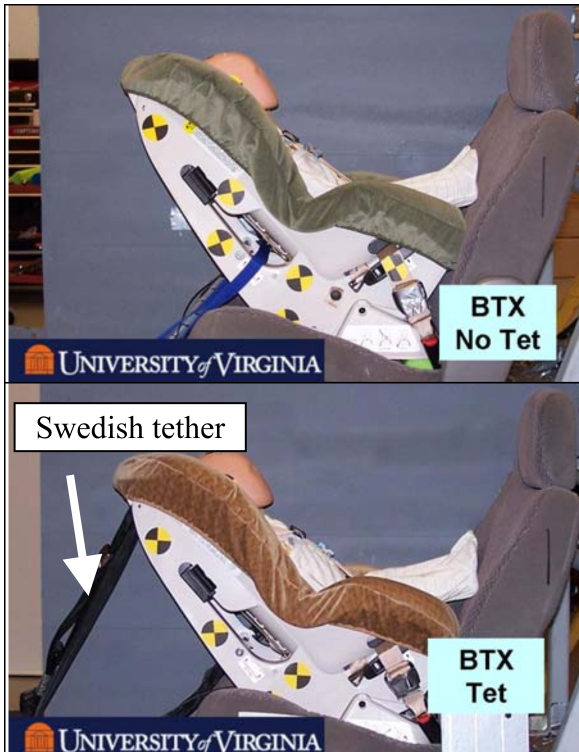

Figure 2. Pre crash photos of the Britax restraint without Swedish tether (Britax No Tet, top) and with Swedish tether (Britax Tet, bottom).

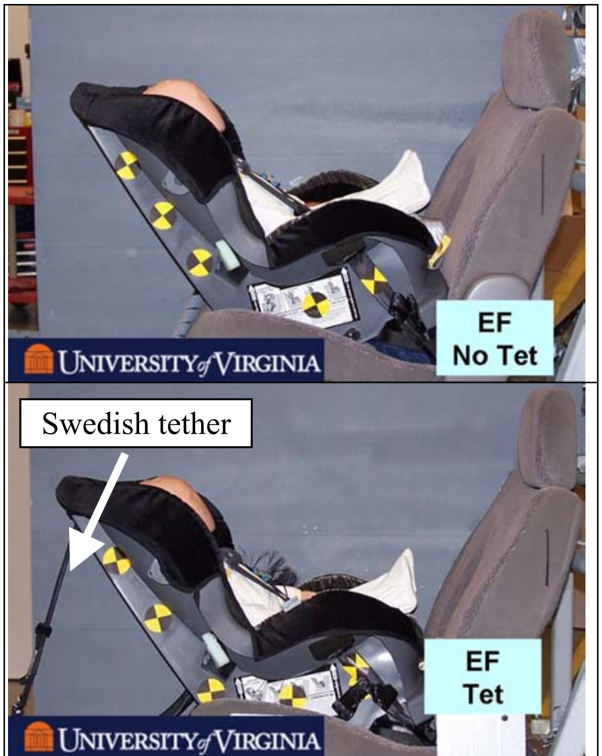

Figure 3. Pre crash photos of the Evenflo restraint without Swedish tether (EF No Tet, top) and with Swedish tether (EF Tet, bottom).

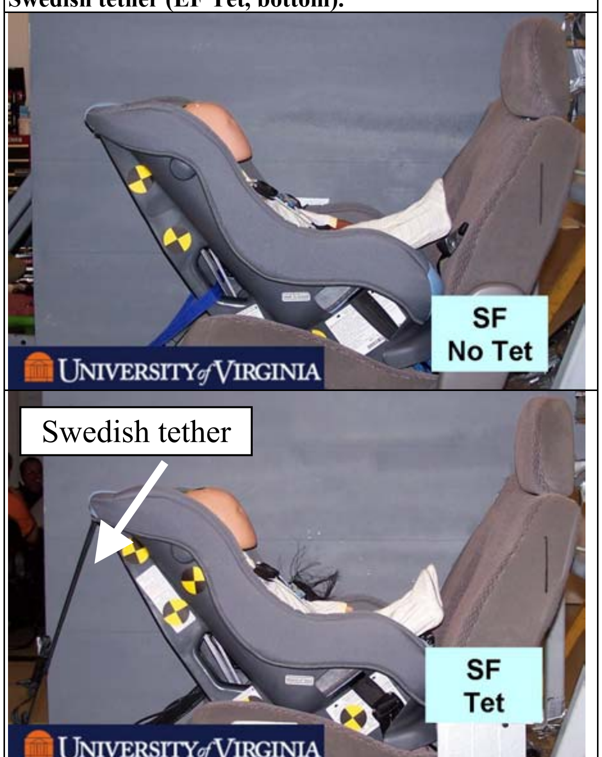

Figure 4. Pre crash photos of the Safety First restraint without Swedish tether (SF No Tet, top) and with Swedish tether (SF Tet, bottom).

Table 1.
Initial position data

	BTX No Tet	BTX Tet	EF No Tet	EF Tet	SF No Tet	SF Tet
Head X position (cm)	56.0	58.0	65.5	66.7	60.0	60.4
CR angle (deg)	40.3	39.5	40.2	39.7	39.9	40.0
Lower LATCH tension (N)	>90	No data	44	>90	>90	67
Swedish tether tension (N)	NA	31	NA	>90	NA	53

RESULTS

The Swedish tether changed the kinematics of each child restraint, but not by large amounts. Figures 5 and 6 show the kinematics of both conditions for the Evenflo restraint. For each restraint the tether reduced the maximum child restraint angle and horizontal excursion distance measured at a point near the child's head (Table 2). The average reduction in movement caused by the addition of the tether was 5.3 degrees and 1.8 cm.

Table 2.
Child restraint kinematic data

	BTX No Tet	BTX Tet	EF No Tet	EF Tet	SF No Tet	SF Tet
Max CR angle (deg)	33	25	18	13	25	22
Max Horiz Excursion (cm)	75.4	73.8	77.4	74.2	70.3	69.9

The sensor injury measurement values are provided in Table 3. The same data are shown graphically in Figure 7, when the percentage of change due to the addition of the Swedish tether is calculated for each injury measure and each restraint. The effect of the tether varied by injury measure and by child restraint. The tether caused an increase greater than 30% in only one instance (upper neck shear), while there were five instances of the tether causing a decrease in an injury measurement by more than 30% (HIC, lower neck shear, lower neck extension).

Figure 5. Evenflo restraint without Swedish tether at 0, 25, 50, 75, and 100 ms.

Figure 6. Evenflo restraint with Swedish tether at 0, 25, 50, 75, and 100 ms. (images flipped to allow easier comparison)

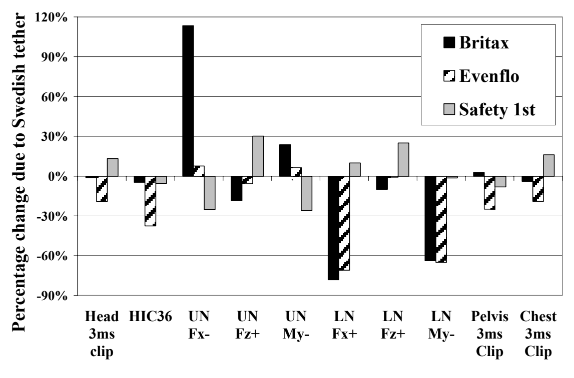

Figure 7. Graph of the effect of Swedish tether on each injury measure, for each restraint.

Table 3.
Dummy injury measurement peak values

	BTX No Tet	BTX Tet	EF No Tet	EF Tet	SF No Tet	SF Tet
Head 3ms clip	52.4	51.7	76.7	62	55.9	63.3
HIC_{36}	560	534	690	431	436	412
UN Fx	-220	-468	-372	-400	-409	-306
UN Fz	1395	1137	1332	1255	1190	1548
UN My	-13	-16	-12	-13	-13	-10
LN Fx	324	71	460	133	437	481
LN Fz	1482	1335	1469	1456	1299	1623
LN My	-11	-4	-14	-5	-14	-14
Chest 3ms clip	47.7	46	55.3	44.8	40	46.2
Pelvis 3ms clip	44.8	46	67.3	50.5	52.5	48.2

There were secondary peaks which occurred when the tether went into tension during rebound. However, these peaks never approached the peak values which occurred earlier in the test.

DISCUSSION

Each restraint was positioned on the vehicle seat with two primary objectives. The first was to position the restraint with consistent angles because installation angle is critical for young children, and because restraint angle significantly affects injury biomechanics. The second was to attach the child restraint to the vehicle as tightly as possible. The tension in the Swedish tether and the removal of the foam spacer changed the restraint's interaction with the vehicle seat, and resulted in different lower LATCH tensions. These varying tensions, however, are the real world by-product of the addition of the Swedish tether and represent a fundamental factor that should be included when comparing the two restraint conditions.

The addition of the tether had the practical benefit of allowing better control of the child restraint angle. Further studies are necessary, however, to ensure that the addition of the Swedish tether does not result in other misuse scenarios. Although the tether tension is minimal during installation and decreases to zero during the primary portion of the frontal crash, strength requirements of the anchor during rebound and in rear impacts must be analyzed.

The addition of a Swedish tether changed the kinematics of the child restraints, although the results varied between the child restraints tested. Rotations and excursion distances of the upper portion of the child restraint were reduced, which would reduce the chance of the child restraints striking vehicle structures such as front seats or the vehicle dash.

The effect of the Swedish tether on injury measures was less consistent. The addition of the tether generally caused an earlier onset of accelerations, but there was not a concomitant decrease in peak acceleration. The effects varied across injury measures and across child restraint model. Only six values (out of 30 calculated) changed by more than 30%. In five of these six instances, the tether resulted in reductions in injury measures. All but one of these instances occurred in the neck shear or moment measures, which are likely the least biofidelic sensors in the CRABI dummy. Thus, while the results varied, the overall effect of the Swedish tether was a negligible reduction in injury severity. Further testing on multiple vehicle seats would provide more support for these findings.

Although not measured as part of this study, the tether had significant effects on the lateral and vertical coupling of the child restraint. Although different coupling methods were tested, Kelly et al. (1995) showed that increased coupling of the child restraint to the vehicle improved test results in side impacts. The increased rigidity afforded by Swedish tethers would be expected to have benefits in side crashes and rollovers, but this area requires more research.

CONCLUSIONS

The results provide evidence that use of a Swedish tether causes a positive but small benefit on the injury risk to children in RFCRs in frontal crashes. The advantage of tethers during installation and possibly in other crash types (side impacts, rollovers) suggests that the use of Swedish tethers in RFCR could be beneficial. Further work is needed to consider issues such as misuse, tether anchors, and the effect in other crash modes.

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